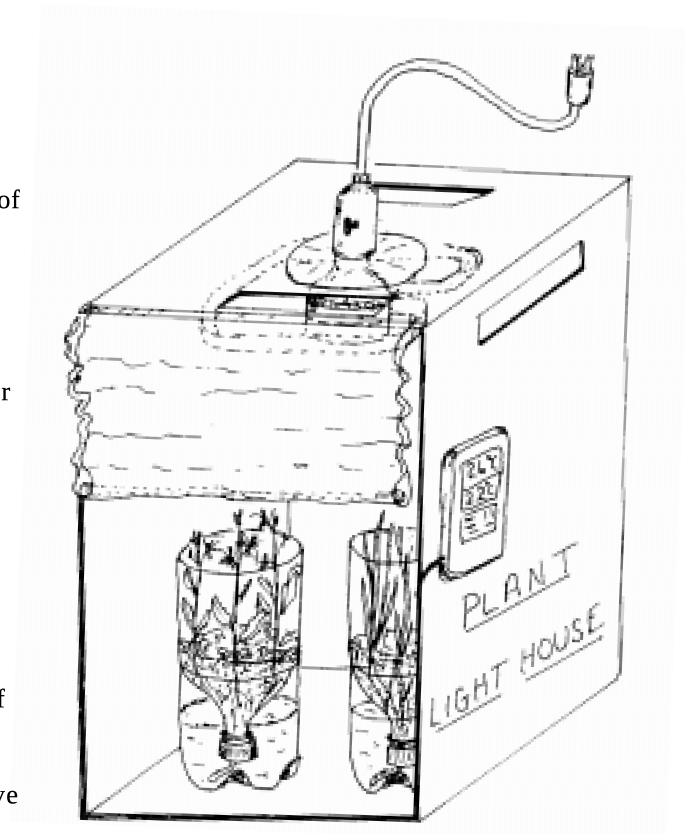
Farming In Space

Introduction

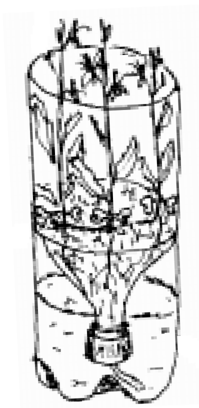
This activity originates from NASA's interest in long-term, manned flight and potential colonization of the moon and planets. Plants can be an important part of bioregenerative life support systems in which food is produced and human waste recycled. To this end NASA is supporting the development of experimental equipment designed to grow plants on the Space Shuttle and the International Space Station. At the same time that engineers are designing equipment for plant growth, plant scientists are evaluating various species for their potential and plant breeders are creating plant varieties that may be suitable in life support systems.



Plant Light House
The simulated Biomass Production System

An example of one of these systems in which Fast Plants and dwarf wheat will be evaluated experimentally on the space shuttle in the coming years is the Biomass Producation System, BPS, designed by Orbitec (Madison, WI). The BPS is a complex piece of equipment with the capability of growing plants in four small chambers in which temperature, light, plant nutrient delivery, CO^2 concentration and relative humidity can be monitored and controlled.

Scientists Gary Stutte, Dynamac, and Robert Morrow, Orbitec, lead a team of other scientists and engineers in an experiment in which the Super Dwarf wheat developed by researcher Bruce Bugbee of Utah State University will be grown and evaluated in the BPS together with dwarf Fast Plants, AstroPlants.



Hydroponic Production Unit

The Educational Activity

The **Farming in Space** activity has been designed to coordinate with the flight experiment. It offers teachers and students a chance to examine a number of basic principles and concepts in plant biology and crop production through hands on experiments using a simulated Biomass Production System and the same seed stocks that the researchers will be using during the flight experiments. Questions that students can examine are similar to those of interest to the scientists and the materials used will reinforce students' understanding of proportionality and statistical summation. The basic experiment is suitable for upper elementary students and higher grades.

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Crop Production

An important concept in crop production that is the focus of these activities is **biomass productivity.** Biomass is the amount of living material (mass) produced by a system of living organisms. Comparisons of the ability of wheat and brassica to use the energy of light in the conversion of carbon dioxide, water and mineral elements into *plant biomass* will be made. Plant biomass is normally measured as *total dry mass* (both roots and shoots) of the plant, or it can be a defined portion of the plants such as the dry mass weight of plant tops only.

A refinement in our understanding of plant biomass is the concept of **harvest index**, which is defined as the proportion or fraction of a specially used part of the plant, e.g., seed, fruit or vegetative part in relation to the total plant, including roots. Normally dry mass is used as the basis for estimating harvest index. A commonly used modification of harvest index is the fraction of usuable part in proportion to the total dry mass of the harvested tops. For example, if a bean plant without roots weighed 100 grams when dry and provided 50 grams of dry beans, then the harvest index is: **HI = 50g ÷ 100g = 0.5**

Another important concept deals with the efficiency with which various species are able to utilize the energy of light for the conversion of CO^2, water and nutrient into biomass. In this experiment the **Energy Conversion Efficiency**, ECE, of two species will be compared — wheat a monocot, brassica a dicot. In the Plant Light House, for example (on page 12), total light energy in the system can be estimated by multiplying the wattage of the light bulb in the Light House by the total number of hours that the plants have been growing at the time of their harvest. In this way a conversion efficiency can be determined based on grams of plant biomass for each watt hour of energy. **ECE of plants = total dry mass of plants (roots and shoot) divided by the total watts over the growing period.**

Design of the Experiment

The **basic experiment** will be to grow the two varieties of Fast Plants and two varieties of dwarf wheat for three weeks to follow their development, and to compare their fresh and dry weights. The four hydroponic growing systems, hereafter referred to as the **Hydroponic Production Units** or **HPU's** will reside within the **Plant Light House** (the simulated Biomass Production System). One of the four seed stocks will be grown in each HPU. The planting design of the overall experiment allows many different kinds of comparisons to be made.

Elementary, middle and high school teachers should determine which of the suggested observations and measurements are desirable for their students to make, based on age, time constraints, etc. Although the protocol is written for both sets of plants to be harvested at 21 days, the length of the experiment may vary, depending on environmental conditions in the HPU and on what teachers or students choose to observe. The growing time may be extended for as long as desired, even up to when the dwarf wheats are mature, approximately 70-100 days. (note: the wheat will become too tall for the HPU if it is allowed to grow to maturity.)

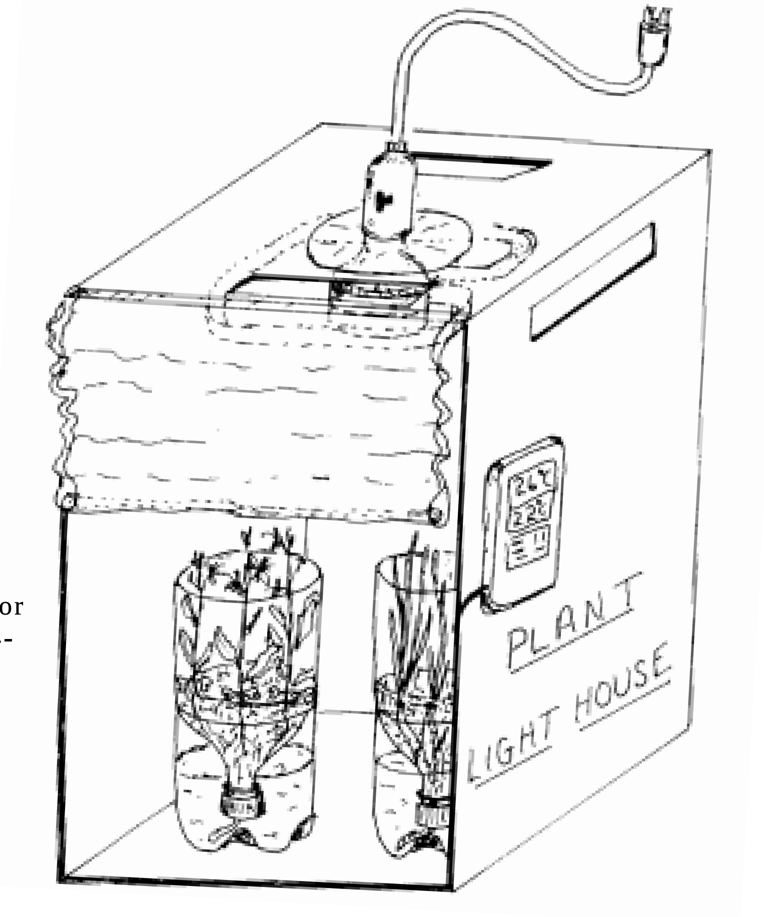
Basic Farming in Space Experiment:

1. building a simple, low cost plant growth box, known as the **Plant Light House**
2. constructing 4 hydroponic nutrient plant systems, HPU's, from 2-liter soda bottles
3. planting four different seed stocks
   - dwarf wheat — high yielding, variety, Apogee
   - dwarf wheat — lower yielding, Super Dwarf
   - Fast Plants — variety, Basic *Brassica rapa,* Rbr
   - Fast Plants — dwarf variety, AstroPlants
4. recording environmental and growth events
5. comparing fresh and dry weights

The experiment is designed to be rich in observations about plant growth, in data taking, simple proportional analysis, and in statistical summation and comparisons between and among the four experimental systems. Growth can be observed and measured using parameters such as height, number of leaves and estimates of root growth. The HPU bottle system allows root growth to be observed easily. At harvest, fresh and dry mass of plant roots and shoots will be measured and may be analyzed to examine various concepts in crop production.

Getting Started

Construction of the **Plant Light House**



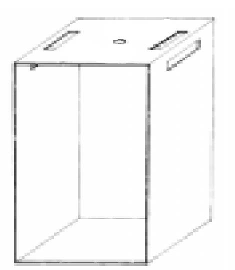
Plant Light House

Materials

- one empty "copy paper" box, e.g., Xerox
- aluminum foil
- electrical cord with socket
- plastic plate or lid
- glue stick
- clear tape (3/4")
- scissors
- 30 watt fluorescent circle light (Lights of America) or a 39 watt GE circle light

Construction

1. Cut a 1 inch hole in the center of a plastic plate or lid and trim off edges to make approximently a 4-5 inch disk with a center hole.
2. Cut several 4 X 14 cm ventilation slots in top, upper sides and back of box as shown.



3. Cut a 1 inch diameter hole in the center of box.
4. Apply glue stick to the each inner surface and paste in aluminium foil to cover entire surface. Use clear tape to reinforce corners and edges.
6. Insert light fixture base through hole in top and through plastic plate. Secure fixture by attaching socket.
7. Tape an aluminum foil or reflective full length mylar curtain over front from the top front edge of box.
8. Strengthen curtain edges with tape. Tape or clip weights (e.g., large nails) on bottom of curtain. Your Light House is ready!

Light Ouput

Irradiance as Photosynthetic Photon Flux, PPF, in the Plant Light House falls within the **ideal** to **adequate** range (100-200 μMol m^2 s^{-1}) using either a 30 or a 39 watt circle light. (See WFPID *Seeing the Light)*

Distance from light	Light Fixture **30 watts**, Light of America	 **39 watts,** GE
10 cm	170 μMol m^2 s^{-1}	200 μMol m^2 s^{-1}
20 cm	150 μMol m^2 s^{-1}	170 μMol m^2 s^{-1}

Construction of the HPU

Materials

- 4, 2-liter soda bottles
- unpolished cotton string or Watermat® for capillary wicks*
- vermiculite, medium grade horticultural
- planting medium, e.g., peatlite, Scotts Redi Earth
- pipette for watering
- Peters 20-20-20 Professional fertilizer
- 1-3 dried bees and toothpicks for making beesticks
- 1 pair of tweezers

Seed Stocks needed

- 20 AstroPlants seeds*
- 20 basic *Brassica rapa* seeds, Rbr*
- 10 dwarf wheat seeds, Apogee**
- 10 dwarf wheat seeds, Super Dwarf**

* available from Carolina Biological Company
1-800-334-5551
** available by contacting Steve Klassen at USU Research Greenhouse, 1410 N, 800 E, Logan, UT 84341, email: stevek@cc.usu.edu

Construction

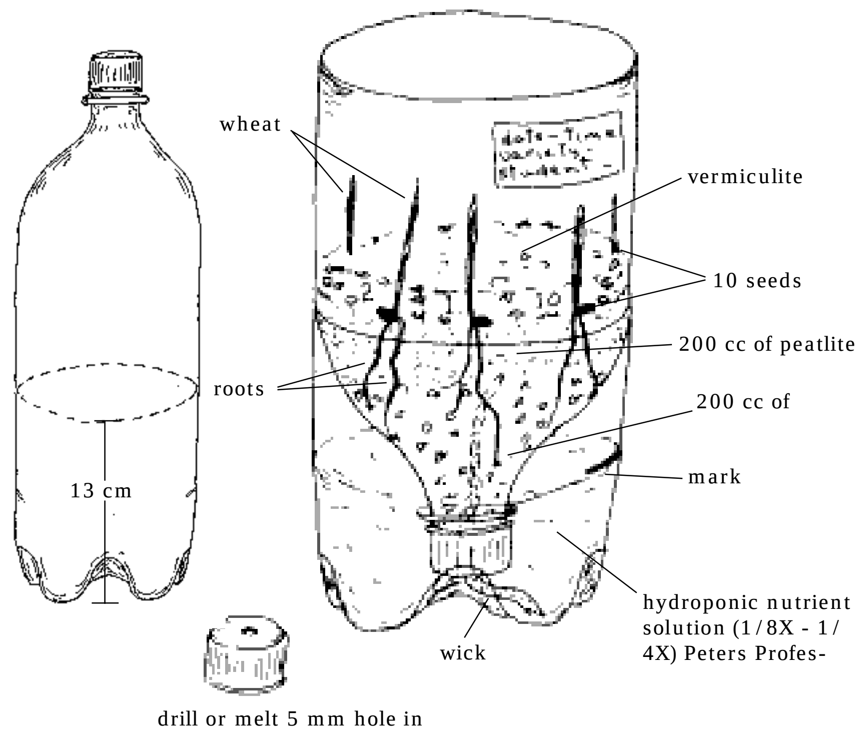
1. Cut four 2-liter soda bottles so that the bottoms are 13 cm. tall. These will serve as the reservoirs for the hydroponic nutrient solution. The top half of the bottle will be inverted into the reservoir as the growing funnel and hold the vermiculite and planting medium.

2. Drill or melt a 5 mm hole in the bottle cap. Screw bottle cap onto bottle top.

3. Insert a string wick (or other capillary wicking), approx. 0.5 cm X 10 cm long, through the hole in the bottle cap. [Check the string you have purchased before planting up, to be sure that it wicks well.]

4. Invert the bottle top (growing funnel) and place in the reservoir (bottle bottom.) The wick should extend from the reservoir bottom into the inverted funnel produced by the bottle top.

Hydroponic Production Unit, HPU



Pre-Planting

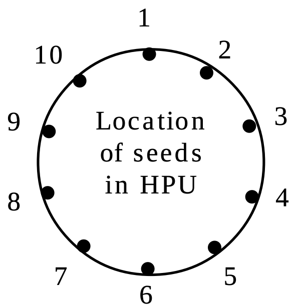
(Note: For uniform germination of Super Dwarf wheat Dr. Bruce Bugbee recommends pretreating the seeds by placing them in a wet paper towel in a plastic bag for 48 hours in the refrigerator prior to sowing in the HPU.)

Planting

1. Layer 200 cc. of vermiculite into the funnel and then layer 200 cc. of peatlite on top of the vermiculite. (Or use whatever “soil” you normally use for Fast Plants.)

2. Gently soak the soil and vermiculite with water until it drips from wick at the bottom of the growing funnel. This is called the *runoff*.

3. Uniformly distibute 10 Apogee wheat seeds in one funnel at the outer edge of the soil up against the clear wall and distribute 10 Super Dwarf seeds similarly into another funnel. Space seeds evenly around the edge approximately 3 cm apart.



4. Gently press the seeds into the soil, but do not bury them. Seeds should now be visible around the perimeter of the bottle through the clear wall of the bottle.

5. Repeat the procedure for both varieties of brassica seeds, except that two seeds should be dropped at each of the 10 evenly distributed locations around the perimenter. (They will later be thinned to one at each position.) Also, the brassica seeds should be pushed to the wall of the bottle with a forceps or toothpick before pressing them gently into the soil. They should be visible through the wall of the bottle.

6. Each of the four HPUs should now contain a separate variety of plants.

7. Cover wheat and brassica seeds with a 1 cm layer of vermiculite.

8. Gently moisten from above until water again drips from the the wick at the base of the funnel. Pour off any excess water remaining in the reservoir and replace it with 400 ml of 1/8 strength Peter's Professional fertilizer (hydroponic nutrient solution). [To make full strength or 1X Peters, dissolve one soda bottle cap full of Peters crystals into one liter of water. Dilute to 1/8X for hydroponic solution.]

9. Mark the level of the hydroponic nutrient solution on the outside of the reservoir with a marking pen.

10. Place a label on the completed HPU indicating the date and hour of planting, the variety of seed/plant in the particular HPU, and identify the student/group.

11. Put the HPU's in the Plant Light House. (Keep light on 24 hours a day.)

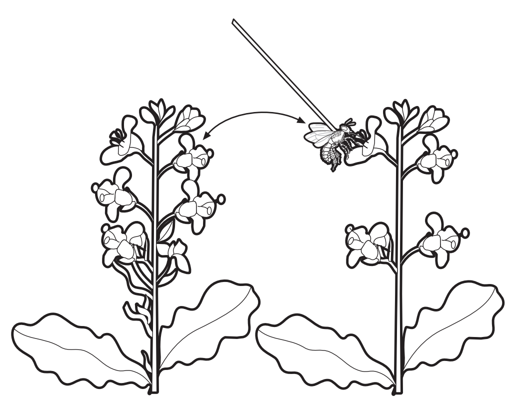
Observing, Measuring and Monitoring

1. Be prepared to observe your germinating seeds each day, and make appropriate records in your log. Many interesting comparisons can be made between wheat and brassica as well as between the two wheat and two brassica varieties. For example, note the time and way seeds germinate, the root and shoot growth patterns.

2. Monitor and record the temp inside the HPU's each day as well as the ambient or room temp. (We use an indoor/outdoor digital thermometer from Radio Shack.) If average temperatures within the HPU's reach 30˚C/ 85˚F, additional ventilation slots can be cut in the top and upper portions of the Light House.

3. Observe the level of the nutrient solution. The amount used by the plants and lost to evaporation can be measured and graphed. Replace used solution as needed. Algal growth in the nutrient solution can be inhibited by wrapping the reservoir in aluminum foil or dark paper to exclude light.

4. Brassicas will begin to flower about 14 days after seeding. When flowers on more than two Fast Plants are open, pollination should begin and should continue every two or three days among all open flowers for at least a week. Pollinate with a beestick made by gluing a dried bee to the end of a toothpick. Collect pollen from the flowers of one brassica plant and move it others. Alternatively, pipe cleaners, Q-tips, or very small pieces of cloth (velveteen) could be used for pollinating.



5. Note: Heads of wheat normally begin to emerge after 23 days. (Wheat is self-pollinated and does not require any pollination activity.) For the basic biomass experiment, we recommed terminating the experiment about 3 weeks after sowing, before the wheat begins to head as flower heads. (Apogee elongates to about 18 inches. Super Dwarf heads at about 12 inches above the soil level.

Harvesting

1. Twenty-one days after planting, harvest plants from each HPU by cutting them off at soil level. Keep each group of plants separate and label them carefully. Be sure all dry and dead leaves are collected separately from each HPU throughout the growth period and saved for weighing.

2. Weigh the plants from each HPU separately.
   - Fresh weights — At harvesting, quickly place the plants in a preweighed plastic bag. (Zip locks work well.) Weigh the total fresh mass of the plants, then subtract the weight of the bag.
   - Dry weight — Plants should be loosely placed in a preweighed brown paper bag and put in a low temperature (200˚F) oven for two days or until they reach constant weight (no more weight loss occurring.) For dry weight measurements, a balance capable of measuring milli-gram or centigram quantities is desirable. (Chemistry classes have such balances.)

3. Compare the relative weights of each group of plants. Draw your conclusions.

Suggested Observations, Measures, Analyses and Comparisons

The following are aspects of the environment and items in growth and development that could be observed, measured, recorded, analyzed and displayed as a function of time (days after sowing) and then compared.

1. Environmental monitoring

- light = daily energy input, watts/24 hr cumulative energy input (total watts)
- temperature, daily
- nutrient solution - usage (ml/day)
- appearance of algae, pests, etc.

2. Developmental events

- germination
  - first emergence of root and shoot
- first leaf, second leaf, etc.
- flower buds (brassica) or head (wheat)
- flowers open
- pod elongation
- appearance of branches on stem (brassica), tillers (wheat)
- yellowing of older leaves

3. Measures of growth

(averages for 10 plants)

- plant height
- leaf number
- root length, root number
- number of flowers open
- number of seed pods enlarging
- number of seeds

4. Measures of biomass

(average of 10 plants at harvest)

- fresh weight of tops
- dry weight of tops
- fresh weight of roots
- dry weight of roots
- dry weight of seed (brassica)

5. Analyses of biomass (within a variety)

- dry weight/fresh weight ratios, tops, roots
- roots/tops ratios
- harvest index of tops, dry
- harvest index of seed (seed weight/ total plant dry weight)
- calculate energy efficiency conversion (grams dry weight/watts)

6. Comparisons (between varieties and species)

- dry weight/fresh weight
- root/top ratios
- total biomass
- harvest indices
- energy efficiencies

Questions

- What are some of the factors that must be taken into consideration when making a decision as to which crop variety or species to choose to accompany humans on a long space flight mission? Support your statements with evidence gained from this experiment or describe an experiment that would provide you with evidence to support your decision.

- What other experiment would you run to strengthen the decision that you would be making?

- How confident are you of the evidence that your experiments would provide? Explain.